WINVENT
THERMAL ANALYSIS OF PROTECTIVE GLAZING

USER'S MANUAL

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INTRODUCTION

Win-Vent is an Excel Spreadsheet that calculates the temperature distribution across the center of a single-glazed or double-glazed sealed or vented window. The program allows the user to change the indoor and outdoor temperatures, and the sky condition between clear and cloudy. The user can input different glass types, gap widths, and glazing sizes. WINVENT assumes the double-glazed units are filled with air. The input to WINVENT and results are in metric units.

HARDWARE AND SOFTWARE REQUIREMENTS

The program is a Microsoft Excel 2000 application. To run the calculations, the Excel Solver tool must be installed. The software program is less than 500 kilobytes and will run on any computer with Microsoft Excel 2000 installed.

QUICK START

WINVENT (V1.0): PROTECTIVE GLAZING ANALYSIS

DOUBLE GLAZING

SAVE

INPUT DATA ID: 18

Environmental Conditions

STEP 4 STARTS HERE

Inside Temperature (C)	25
Outside Temperature (C)	36
Outdoor Relative Humidity (%)	68
Indoor Relative Humidity (%)	65
Windspeed (m/s)	0.4
Incident Solar (W/m2)	300
Venting Condition (Select)	Outside

Results

Surface 2 Temperature (C)	41.0
Surface 3 Temperature (C)	39.8
Gap Temperature (C)	40.2
Gap Dewpoint Temperature (C)	29.0
Interior Dewpoint Temp. (C)	18.0

Glazing System

		Thick (mm)	Cond. (W/m-C)	Solar Trans.	Front Refl.	Back Refl.	Front Emitt.	Back Emitt.	
Layer 1	New Lexan #1	5.79	0.20	0.75	0.08	0.08	0.88	0.88	Exterior
Layer 2	52108.86p	2.90	0.90	0.37	0.17	0.17	0.83	0.83	Interior

Note: front is facing the outside, back is facing the inside

Gap Width (mm)	12.5
Height of Glazing System (mm)	2286
Width of Opening (mm)	12.50
Area of Glazing (m2)	22.86

Figure 1 Top half of WINVENT screen.

To install and use the program, follow these steps and refer to Figure 1. *Only enter data in cells with a yellow background*. All other cells are fixed.

1. Copy the file WINVENT-6.XLS to your hard drive.
2. Start Excel and open WINVENT-6.XLS.
3. Select the SINGLE (single glazing) or DOUBLE (double glazing) worksheet (click on tab).
4. Enter the indoor and outdoor environmental conditions: inside temperature, outside temperature, relative humidity, wind speed, and incident solar radiation. The relative humidity is either that measured in the gap or an estimated value.
5. For double-glazing windows, select the venting condition: Inside, Outside or Sealed.
6. Click on the Layer 1 button and select the glass type from the list. For double-glazed windows, Layer 1 is to the exterior and Layer 2 is the interior. The spreadsheet will load the optical data into the cells automatically.
7. For double glazing, enter the Gap Width (mm) between the panes of glass.
8. Enter the Height of the Glazing System (mm.).
9. For single or double glazing, enter the height (mm) of the glazing system.
10. For double glazing, enter the Width of the Vent Opening (mm).
11. For single or double glazing, enter the Area of the window (m^2).
12. To run the calculations, select Tools from the Excel menu and choose Solver from the Tools menu. Hit Enter to start Solver. Solver will iteratively solve for the temperature distribution across the center of the glazing system.
13. Click on the SAVE button to write the results to the Report screen. Click on the Report screen tab to view the systems you have modeled.

HOW TO USE WINVENT

The following provides a more detailed description of WINVENT and how to use it. The program was originally developed to model passively ventilated, double-glazed systems representative of stained glass windows with protective glazing. The single-glazed model was added to compare the performance of windows without protective glazing. The thermal and optical properties for clear and bronze glass, and various stained glass samples are included in the Glass worksheet to simplify the modeling of glazing systems (see section below on Glass Data). The results from the calculations can be saved to the Report worksheet in order to analyze the results and compare glazing systems.

Worksheets within WINVENT

WINVENT is an Excel workbook with four worksheets. The worksheets are the following:

- **DOUBLE**: used to analyze sealed and vented, double glazing
- **SINGLE**: used to analyze single glazing
- **Glass**: glass data for use in constructing glazing units in the SINGLE and DOUBLE worksheets.
- **Report**: worksheet for storing results from glazing analysis using Save button on SINGLE and DOUBLE worksheets.

Access a worksheet by clicking on the tab at the bottom of the worksheet. The thermal analysis is performed from the SINGLE and DOUBLE worksheets using the Excel Solver.

WINVENT Macros

Most of the calculations in WINVENT are performed by Visual Basic macros contained in the WINVENT workbook. When WINVENT is opened in Excel, respond "Yes" to the question of whether or not you want to enable the macros. Calculations have also been programmed into certain cells throughout the worksheets; ***please remember to only change those cells highlighted in yellow.***

Environmental Conditions

WINVENT allows the user to define the indoor and outdoor temperature, humidity and solar conditions, and the Excel Solver determines the temperature distribution across the glazing unit based on these conditions. The environmental conditions are entered in the top portion of the Single or Double worksheets. The required information is listed in Table 2. Table 2 also defines each field and gives the associated input units.

Table 1 Environmental Conditions

Field	Definition	Units
Inside Temperature	Indoor room air temperature	°C
Outside Temperature	Outdoor air temperature	°C
Outdoor Relative Humidity	Moisture level in outside air	RH
Indoor Relative Humidity	Moisture level in inside air	RH
Wind speed	Velocity of outside air	m/s
Incident Solar	Solar energy incident of glazing system	W/m^2

Glass Data

WINVENT includes a library of different glass types to simplify the construction of a single-glazed or double-glazed window (see Glass worksheet). The glass thermal and optical properties in WINVENT are based on measured data from stained glass samples, with the exception of the first four records (Table 2). The first four records are generic glass types taken from the WINDOW 4.1 glass library. The thermal and optical properties of the stained glass samples were measured per the National Fenestration Rating Council procedure, NFRC-300 (NFRC 1997). The thermal property is the thermal conductivity (Cond.). The optical properties include the solar transmittance (Solar Trans.), solar front reflectance (Front Refl.), solar back reflectance (Back Refl.), thermal infrared emittance of the front and back (Front Emitt. and Back Emitt.). Refer to Figure 2, section 1 which shows the properties of each glass layer in a double-glazed unit.

WINVENT uses the conductivity of the glass and the thermal infrared emittance of the glass surfaces to calculate the heat transfer across the glazing system. It also uses total average solar optical properties, specifically the solar absorptance in each layer, to calculate the inward flowing absorbed solar radiation. Refer to Figure 2, section 2, which shows the total average solar properties of a double-glazed unit. The total average solar properties are calculated in accordance with NFRC 300.

Table 2 WINVENT Glass Data

ID	Glass Name	Thickness (mm)	Description
100	BRONZE_3.DAT	3.12	3 mm typical bronze glass
101	BRONZE_6.DAT	5.74	6 mm typical bronze glass
102	CLEAR_3.DAT	3.05	3 mm typical clear glass
103	CLEAR_6.DAT	5.72	6 mm typical clear glass
1000	Lime	3.1	Spectrum glass color code #329-2S; light green and white, wispy, opalescent
1001	Blue-White	3.12	Wissmach Glass sample #188-D; light blue/opal, opalescent
1002	Opal	3.63	Wissmach Glass sample #WO-55; amber/green/opal; opalescent
1003	DkBlue	2.69	Wissmatch Glass sample #341; medium blue, cathedral
1004	Blue	2.84	Wissmatch Glass sample #118; light blue cathedral
1010	Old Lexan #1	4.42	yellowed lexan
1012	New Lexan #1	5.79	new lexan
1020	52108.k70	3.18	Hollander Glass sample #K70ML; medium blue, green, dark purple; opalescent
1021	52108.2	3.18	Hollander Glass sample 3S411-15; root-beer streaky; opalescent
1023	52108.3	2.95	Hollander Glass sample #S307I; feather white iridescent; opalescent
1024	52108.3	2.9	Hollander Glass sample#S317-1; translucent light amber; opalescent
1025	52108.59g	3.53	Kokomo Opalescent Glass sample # 59G; brown, green; opalescent
1026	52108.86p	2.9	Kokomo Opalescent Glass sample# 86P; dark green, pink; opalescent
1027	52108.b31	3.23	Hollander Glass sample #B3123; white opal, orange opal, deep forest green; opalescent
1028	52108.k11	3.94	Hollander Glass sample #K11MLX; medium wispy pale amber; opalescent
1029	52108.1	2.72	Kokomo Opalescent Glass sample #12; green,blue; opalescent
1030	nps15863.1	1.7	American Stencil Glass circa 1874
1031	nps15863.2	2.67	German Painted Glass circa 1890
1032	nps15863.3	4.95	Confetti Glass circa 1895
1033	nps15863.4	3.45	American Painted Glass circa 1915
1034	nps15863.5	1.75	Cobalt Flashed Glass circa 1872
1035	nps15863.6	5.74	German Antique Glass circa 1890

Glazing System

1

		Thick (mm)	Cond. (W/m-C)	Solar Trans.	Front Refl.	Back Refl.	Front Emitt.	Back Emitt.	
Layer 1	CLEAR_3.DAT	3.05	0.90	0.83	0.08	0.08	0.84	0.84	Exterior
Layer 2	52108.86p	2.90	0.90	0.37	0.17	0.17	0.83	0.83	Interior

Note: front is facing the outside, back is facing the inside

Calculate System Solar Transmittances, Reflectances, and Absorptances

2

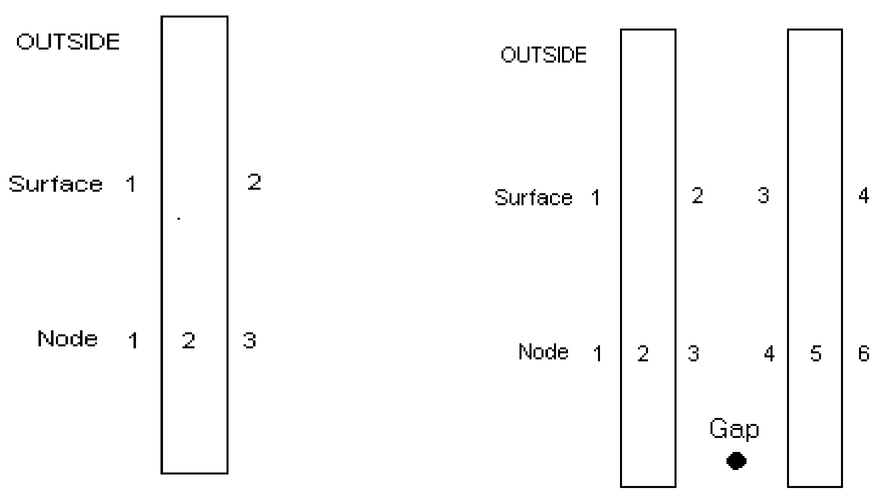
	System	Exterior Layer	Interior Layer
Transmittance	0.32		
Reflectance		0.20	0.18
Absorptance		0.10	0.38

Figure 2 Thermal and optical properties of the glass layers in a double-glazed unit (1), and the total average optical properties of the double-glazed unit (2) as they appear in WINVENT.

Temperature Results

The temperature distribution across the glazing system is calculated based on solving for the heat transfer across the system. At each node, an energy balance is performed (Qtot). The convective (Qc), radiative (Qr), and conductive (Qk) energy flows at each node are included as well as the solar radiation absorbed within each glazing layer.

Figure 3 shows the numbering system for the surfaces and nodes for single glazing and double glazing. Note that the outside is assumed to be on the left. At the top of the worksheet, temperatures are shown for select surfaces, the gap in the case of double glazing, and the corresponding dewpoint temperature. Towards the bottom of the worksheet, the temperature at each node is displayed. The results following the table of temperature nodes are explained in detail under the following sections on single and double glazing.



Single Glazing

For single glazing, i.e. single pane, click on the SINGLE tab and go to the top of the worksheet. There are three distinct sections that require input: 1) environmental conditions, 2) glass data, and 3) glazing system dimensions (Figure 4).

WINVENT (V1.0): PROTECTIVE GLAZING ANALYSIS

SINGLE GLAZING

SAVE

INPUT DATA **ID:** 2

Environmental Conditions

1

Inside Temperature (C)	25
Outside Temperature (C)	36
Outdoor Relative Humidity (%)	60
Indoor Relative Humidity (%)	40
Windspeed (m/s)	3.4
Incident Solar (W/m2)	783

Results

Surface 1 Temperature (C)	38.0
Surface 2 Temperature (C)	37.8
Avg. Gap Temperature (C)	N/A
Gap Dewpoint Temperature (C)	N/A
Interior Dewpoint Temp. (C)	10.5

Glazing System

2

		Thick (mm)	Cond. (W/m-C)	Solar Trans.	Front Refl.	Back Refl.	Front Emitt.	Back Emitt.
Layer 1	CLEAR_6.DAT	5.72	0.90	0.77	0.07	0.07	0.84	0.84

Note: front is facing the outside, back is facing the inside

3

Height of Glazing System (mm)	1956
Area of Glazing (m2)	1.39

Figure 4 Single glazing input fields.

- First, enter the environmental conditions, shown as section 1 in Figure 4.
- Next, select the glass from the Glass worksheet by clicking on the "Layer 1" button, shown as section 2 in Figure 4. The Layer 1 button brings up the list of glass types (see previous discussion on Glass Data).
- Finally, enter the height of the glazing system and the area. Note that the height is entered in millimeters (mm) and the area is entered in square meters (m2).

To run the calculations, use the Solver tool in Excel by clicking on Tools on the main toolbar and selecting Solver. Do not change any of the Solver defaults. These have been set up specifically for use with WINVENT. Figure 5 shows the dialog box for single glazing. Solver changes the temperatures in cells C43, C44 and C45 until the energy balance at each temperature node equals 0.0. (A diagram of the temperature nodes is shown in Figure 3.) The energy balance for each temperature node is contained in cells I43, I44 and I45 under the Qtot column (Figure 6). The resulting temperatures are shown in the T(C) column, cells C43, C44 and C45 (Figure 6).

In addition, the dewpoint temperatures of the interior air and exterior air are shown beneath the Results table (Figure 6). The dewpoint temperature refers to the temperature at which condensation will occur for the specified air temperature and humidity level. A note appears to the right of the dewpoint temperature stating whether or not condensation will occur the exposed glass surface. Condensation will occur when the temperature of the exposed glass surface is equal to or below the dewpoint temperature.

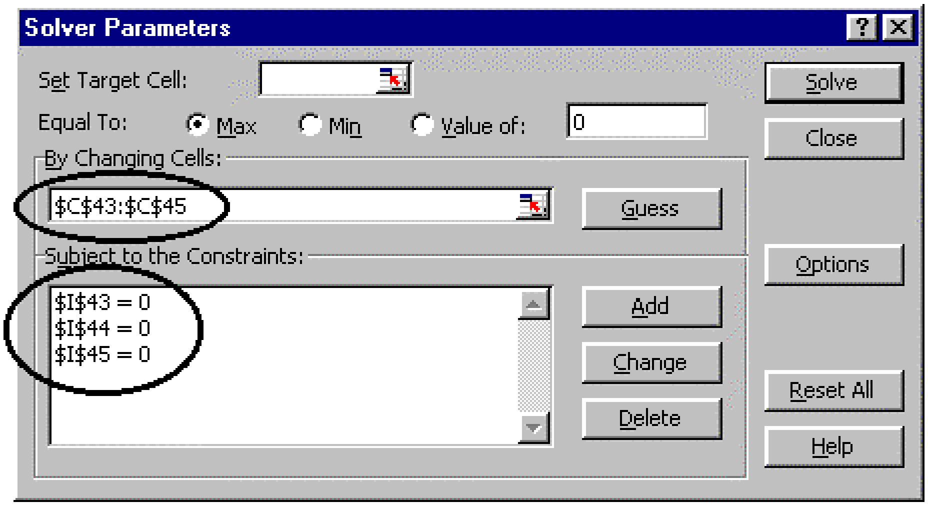


Figure 5 Dialog box for Excel Solver for single glazing.

Results

Temperature Node	T(C)	Qc	Source	Qr	Qk	Solar	Qtot
1	38.0	16.19	446	529	27.6	0	0.0
2	38.1	0	0	0	0.0	125	0.0
3	37.8	-28.87	445	517	-97.7	0	0.0

Dewpoint Temp. of Interior Air (C)	10.5	Condensation on Interior Surface
Dewpoint Temp. of Exterior Air (C)	27.0	No Condensation on Exterior

Figure 6 Temperature results for single glazing.

Double Glazing

For double glazing, i.e. double pane, click on the DOUBLE tab and go to the top of the worksheet. There are three distinct sections that require input: 1) environmental conditions, 2) glass data, and 3) glazing system dimensions (Figure 7).

WINVENT (V1.0): PROTECTIVE GLAZING ANALYSIS

DOUBLE GLAZING

SAVE

INPUT DATA **ID:** 18

Environmental Conditions

①

Inside Temperature (C)	25
Outside Temperature (C)	36
Outdoor Relative Humidity (%)	68
Indoor Relative Humidity (%)	65
Windspeed (m/s)	0.4
Incident Solar (W/m2)	300
Venting Condition — Select	Outside

Results

Surface 2 Temperature (C)	41.0
Surface 3 Temperature (C)	39.8
Gap Temperature (C)	40.2
Gap Dewpoint Temperature (C)	29.0
Interior Dewpoint Temp. (C)	18.0

Glazing System

②

		Thick (mm)	Cond. (W/m-C)	Solar Trans.	Front Refl.	Back Refl.	Front Emitt.	Back Emitt.	
Layer 1	New Lexan #1	5.79	0.20	0.75	0.08	0.08	0.88	0.88	Exterior
Layer 2	52108.86p	2.90	0.90	0.37	0.17	0.17	0.83	0.83	Interior

Note: front is facing the outside, back is facing the inside

③

Gap Width (mm)	12.5
Height of Glazing System (mm)	2286
Width of Opening (mm)	12.50
Area of Glazing (m2)	22.86

Figure 7 Double glazing input fields.

- First, enter the environmental conditions, shown as section 1 in Figure 7. For double glazing, also select the venting condition. The glazing unit may be vented to the inside, the outside, or sealed.
- Next, select the glass from the Glass worksheet by clicking on the "Layer 1" and "Layer 2" buttons, shown as section 2 in Figure 7. The Layer buttons bring up the list of glass types (see previous discussion on Glass Data). Layer 1 refers to the glass to the exterior of the glazing system and Layer 2 refers to the glass to the interior of the glazing system.
- Finally, enter the dimensions of the glazing system, shown as section 3 in Figure 7. The pertinent dimensions include the gap width of the air-filled gap between the panes of glass (mm), the height of the glazing system (mm), the width of the vent opening (mm), and the area of the glazing unit (m2). The length of the glazing system is calculated by WINVENT from the area and height.

To run the calculations, use the Solver tool in Excel by clicking on Tools on the main toolbar and selecting Solver. Do not change any of the Solver defaults. These have been set up specifically for use with WINVENT. Figure 8 shows the dialog box for double glazing. Solver changes the temperatures in cells C43 through C50 until the energy balance at each temperature node equals 0.0. (A diagram of the temperature nodes is shown in Figure 3.) The energy balance for each temperature node is contained in cells I43 through I50 under the Qtot column (Figure 9). The resulting temperatures are displayed in the T(C) column, cells C43 through C50 (Figure 8).

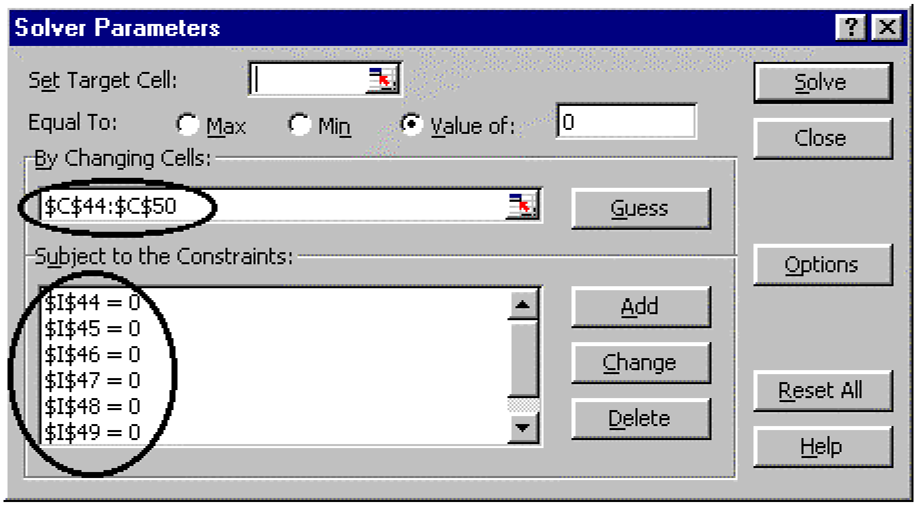


Figure 8 Dialog box for Excel Solver for single glazing.

Beneath the table displaying the temperatures across the glazing system, a number of other temperatures and air velocities are shown (Figure 9). Some of the properties are calculated as Solver determines the temperature distribution. Table 3 lists and defines each of the properties.

Table 3 Double Glazing Results

Property	Definition
Venting Condition	Double glazing is vented to the inside or outside, or the unit is sealed. (Entered under Environmental Conditions)
Temperature in Gap (C)	As determined by Solver from the energy balance at each temperature node (including node in the center of the gap).
Dewpoint Temperature of Air in Gap (C)	Temperature at which condensation will form for air in gap.
Dewpoint Temp. of Interior Air (C)	Temperature at which condensation will form for air in the room. WINVENT states whether or not condensation will occur on interior glass surface.
Dewpoint Temp. of Exterior Air (C)	Temperature at which condensation will form for outdoor air. WINVENT states whether or not condensation will occur on exterior glass surface
Air Velocity in Gap (m/s)	Velocity of air in gap
cfm (m3/s)	Volumetric flow of air in vented gap

Results

Temperature Node	T(C)	Qc	Source	Qr	Qk	Solar	Qtot
1	40.4	21.53	482	545	48.1	0	0.0
2	41.1	0	0	0	0.0	58	0.0
3	41.0	-3.7	486	551	-9.6	0	0.0
Gap	40.2	0.0	0	0	0.0	0	0.0
4	39.8	-1.8	452	545	-7.8	0	0.0
5	39.8	0	0	0	0.0	104	0.0
6	39.6	-32.86	450	527	-111.4	0	0.0

Venting Condition	Outside	
Temperature in Gap (C)	40.2	
Dewpoint Temperature of Air in Gap (C)	29.0	No Condensation
Dewpoint Temp. of Interior Air (C)	18.0	No Condensation on Interior
Dewpoint Temp. of Exterior Air (C)	29.1	No Condensation on Exterior
Air Velocity in Gap (m/s)	0.07	

Figure 9 Temperature results for double glazing.

Saving Results

The glazing system properties and thermal analysis results can be saved to the Report worksheet by clicking on the Save button in the upper right hand side of the Single or Double worksheets. A glazing system can be uniquely identified by assigning an ID to the glazing system. The ID cell is located beneath the Save button.

HEAT TRANSFER ACROSS A GLAZING SYSTEM

The heat transfer between the outside and inside is solved as a set of simultaneous equations because the heat transfer components are temperature dependent. The temperature at each glazing surface and in the center of each glazing layer is determined by performing an energy balance at each temperature node (Figure 1). The energy balance includes conduction across the glazing layers, convection and radiation heat transfer to the surroundings and between glazing layers, and absorbed solar radiation within the glazing layers. The energy balance at each temperature node equals zero, and the unknowns are the temperatures. The equation at each node is a function of the temperature at that node and of the temperatures at surrounding nodes. The temperatures are determined by solving the equations simultaneously. The "Solver" routine in Excel is employed to solve the set of simultaneous equations.

A one-dimensional heat transfer analysis is limited in that it ignores the effects around the perimeter of the glazing system (edge and frame effects), the conductance through the lead came, the variation in glass color (i.e. absorptance and reflectance) of the stained glass window, and the temperature stratification between the top and bottom of the window. Even with these limitations, a one-dimensional heat transfer analysis has been shown to predict surface temperatures that are in good agreement with measurements (Gilberg et.al. 2001).

The International Standards Organization developed a standard to calculate the heat transfer through windows (ISO 15099, 2002). The standard addresses the vented gap condition and describes the differences in the energy balance from the unvented case. The primary difference between the calculations in WINVENT and those in the ISO standard is in the convective heat transfer in the gap. The other difference is the convective heat transfer to the outside from the exterior surface. The individual heat transfer components are discussed below.

Exterior Surface Heat Transfer

The exterior surface of the glazing system exchanges heat with its surrounding environment through convection and radiation heat transfer. For the convective heat transfer from windows on actual buildings, ISO 15099 (2002) recommends the correlation developed by Ito, Kimura, and Oka (1972). We have achieved better agreement with field tests using the correlation by Yazdanian and Klems (1994).

The correlation by Yazdanian and Klems assumes the air velocity, vel (m/s), near the outside surface is equal to the wind speed. T1 is the surface temperature of the outside facing surface of glass and Tout is the outside air temperature in degrees Celsius. The convective heat transfer coefficient, hcout (W/m2-C), is then:

hcout = 5.678 * (((0.096 * ((T1 - Tout)*1.8) ^ (1 / 3)) ^ 2 + (0.203 * (vel/0.447) ^ 0.89) ^ 2) ^ 0.5

The radiative heat transfer depends on the temperature of the sky, the emittance of the exterior glazing surface and that of the sky, and the view factor between the window and the sky. By selecting clear or cloudy, the temperature and emittance of the sky is calculated. Under clear sky conditions, the sky temperature is colder than the outdoor air temperature. Under cloudy sky conditions, the sky temperature is assumed to be equal to the outdoor air temperature. The glazing emittance is typically 0.84, unless the surface is coated. The view factor between the window and sky is assumed to be 1.0. Refer to the ISO 15099 standard (2002) for detail on the radiative heat transfer calculations.

Interior Surface Heat Transfer

The interior surface of the glazing system also exchanges heat with its surrounding environment through convection and radiation heat transfer. For natural convection across the glazing unit, ISO 15099 (2002) refers to the correlations recommended by Curcija and Goss (1995).

The natural convection heat transfer coefficient for the indoor side, $h_{c,in}$ is determined in terms of the Nusselt number, *Nu*.

$$h_{\mathrm{c,in}} = Nu\left(\frac{\lambda}{H}\right)$$

where λ is the thermal conductivity of air and H is the height of the glazing system.

Nu is calculated as a function of the corresponding Rayleigh number based on the height, *H*, of the glazing system, Ra_H.

$$Ra_{\mathrm{H}} = \frac{\rho^2 H^3 g C_{\mathrm{p}} \left| T_{\mathrm{b,n}} - T_{\mathrm{in}} \right|}{T_{\mathrm{m,f}} \mu \lambda} \qquad \text{(dimensionless)}$$

where the various fluid properties are those of air evaluated at the mean film temperature:

$$T_{\mathrm{m,f}} = T_{\mathrm{in}} + \tfrac{1}{4}\left(T_{\mathrm{b,n}} - T_{\mathrm{in}}\right)$$

$$Nu = 0.56(Ra_H)^{1/4} \quad Ra_H <= Ra_c$$

$$Nu = 0.13(Ra_H^{1/3} - Ra_c^{1/3}) + (0.56Ra_c)^{1/4} \quad Ra_H > Ra_c$$

$$Ra_c = 2.5x10^5(e^{0.720})^{1/5}$$

The radiative heat transfer to the inside depends on the room temperature, the emittance of the interior glass surface and the room, and the view factor between the window and the room. The emittance of the interior glass surface is 0.84 as long as it is not coated, and the emittance of the room is 1.0 (blackbody). The view factor between the window and the room is assumed to be 1.0. Refer to the ISO 15099 standard (2002) for detail on the radiative heat transfer calculations.

Gap Heat Transfer

In searching the literature on heat transfer in enclosed and vented cavities, we found nothing published that addresses the case of small vent holes at the top and bottom of a vertical channel. There is work published by Sparrow, et.al. (1984) on vented channels with the top and bottom of the channels open, and by Sefcik, et.al. (1991) on vented channels with openings that are 1/3 (at the smallest) of the width of the channel. Under winter conditions with an outside temperature of 0 °F, an inside temperature of 70 °F, and a 15 mph wind speed, the Sefcik correlation (1991) predicts the highest heat transfer (assuming a 1/3 ratio of opening area to gap width), followed by the Sparrow correlation (1984). The enclosed cavity correlations are fairly close and, as expected, predict less heat transfer than the vented cavity correlations. This assumes the height of the glazing unit is 900 mm and the gap width is varied between 6 mm and 100 mm.

Sefcik (1991) predicts the Nusselt number for a vented cavity as follows:

Nu = 0.33 * Gr ^ 0.261 * Pr ^ 0.345 * (vent / gap) ^ 0.175

where Nu is the Nusselt number, Gr is the Grasshof number and Pr is the Prandtl number for air. Vent is the width of the vent opening in meters and gap is the width between the primary glazing and protective glazing in meters. The Grasshof number is calculated from gravity, g, the thermal coefficient of expansion of air, β, the density of air, ρ, the gap width, the difference in temperature between the gap and the inlet to the gap, and the viscosity of air, ν. The inlet temperature equals the outside air temperature or the inside air temperature.

Gr = (g * β * ρ ^ 2 * gap ^ 3 * Abs(Tgap - Tinlet)) / ν ^ 2

The convection heat transfer correlation is then calculated as:

hcgap = k * Nu / gap

where k is the conductivity of air in W/m-C.

The radiative heat transfer between the glazing layers depends on the temperatures of the surfaces bounding the gap, the emittance of the surfaces, and the view factor between the glazing layers. The emittance of the glazing surfaces is 0.84 as long as they are not coated. The view factor between the surfaces is assumed to be 1.0, which represents infinte parallel surfaces. Refer to the ISO 15099 standard (2002) for more detail on the radiative heat transfer calculations.

Solution to the Energy Balance

For more details on the heat transfer analysis refer to ISO 15099 (2002), Arasteh (1994) and Wright (1995), These references detail the conductive, convective and radiative components of the energy balance. Note that the calculation of the thermal infrared (long wavelength) radiative exchange cannot be ignored in performing such an analysis. The references also demonstrate how to assign temperature nodes and calculate the energy balance at each temperature node. There are numerous approaches to solving for the temperature distribution across a glazing system; WINDOW 4.1 [Arasteh, 1994], VISION [Wright, 1995] and the Excel Solver routine represent just three of the alternatives.

WINDOW 4.1 and *VISION 4* can calculate the total solar transmittance, absorptance and reflectance of the glazing system from detailed spectral data for individual glazing samples. WINVENT calculates the total solar transmittance, absorptance and reflectance of the glazing system from the average solar properties of the individual glazing samples. This approximation has a negligible impact on the results because neither the stained glass nor the Lexan® is spectrally selective.

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